LA-UR-19-24078

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Title:	Radiation Signatures of Potential Nuclear Threats
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Intended for:	One Time Seminar at Colorado State University
Issued:	2019-05-03

Radiation Signatures of Potential Nuclear Threats

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Colorado State University Seminar

April 8, 2019

Abstract

- Brief Overview of the DOE Triage and JTOT Programs
- Gamma and Neutron Signatures in Select Measurements
- Software Demos of FRAM and PeakEasy
- Discussion of GADRAS as an Analysis Tool

DOE Triage Program

- Triage was stood up in 2003 (post 9/11 world)
- Mission is to analyze and adjudicate radiation data from any detector from any location worldwide.
  - Primary focus is to answer the question – “Is this object benign or is it a threat (or potential threat)?”
- Triage is the final step in adjudication (LSS in the Dept of Homeland Security is the first step)
  - When data indicates a threat or a potential threat the DOE Joint Technical Operations Team (JTOT) kicks into gear (formerly NEST)

DOE JTOT Overview

- Will respond to nuclear terrorist threats anytime, anywhere
  - Improvised Nuclear Devices or Stolen Sovereign State Devices
  - Radiological Dispersal Devices (aka “Dirty Bombs”)
  - Radiological Exposure Devices
- Rapid deployment by a multidisciplinary group of high level experts
  - Primary mission is to de-active the threat before harm is done (Render Safe)
  - Following that they begin the processes of attribution (who did this?) and forensics (where did the materials come from?)

Challenges Associated with IND Discovery and Disablement

Los Alamos NATIONAL LABORATORY EST. 1943

- An IND is <u>unlikely</u> to look exactly like a typical modern day state-sponsored nuclear device
- The design possibilities are vast and the design will greatly impact the radiation signatures:
  - Can it be detected/found with gamma ray detectors
  - Can it be detected/found with neutron detectors
  - Will there be other signs this is a nuke? Size? shape?
- An IND may not even produce nuclear yield (if we are lucky) but any terrorist attempt must be aggressively adjudicated (urgency is VERY high!)

Challenges of Finding the Nuke

- Obviously we look for gross gamma and neutron count rates statistically greater than background
- Many factors influence the intensity of the radiation as it comes off the device
- Detection distances range from a few to several 10's of meters
  - Crude devices could very well be more difficult to detect than a modern miniaturized device
- Good Intel on approx location would be HUGE

Neutrons Are Our Friend

- They are more difficult to shield than gammas and inherent backgrounds rates are very low
- Weapon grade Pu emits ~ 60,000 n/s/kg (nearly all from ^{240}Pu)
- HEU (90-93%) emits ~ 1 n/s/kg
- ^{233}U emits ~ 1 n/s/kg
- ^{237}Np emits < 1 n/s/kg
- ^{238}U emits 13.7 n/s/kg

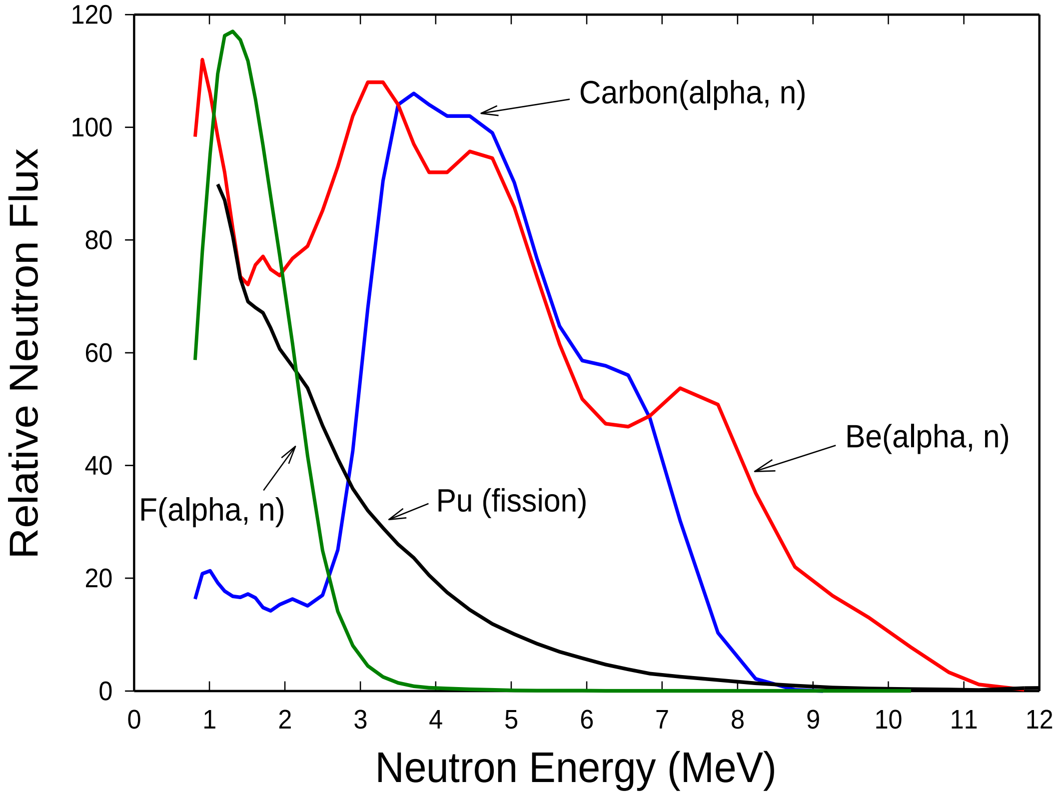
Analyzing Neutrons

- Once a Nuke or potential threat is found and neutrons are detected (or even if they aren't) it is important to determine if the special nuclear material (SNM) is a multiplying mass
  - i.e., are there more neutrons being emitting by induced fission (as opposed to just spontaneous fission) because enough material is present and k_{eff} is approaching some fraction of criticality limits
- Multiplication helps indicate if the device might or might not work!
- Fission neutrons are correlated in TIME

Analyzing Neutrons

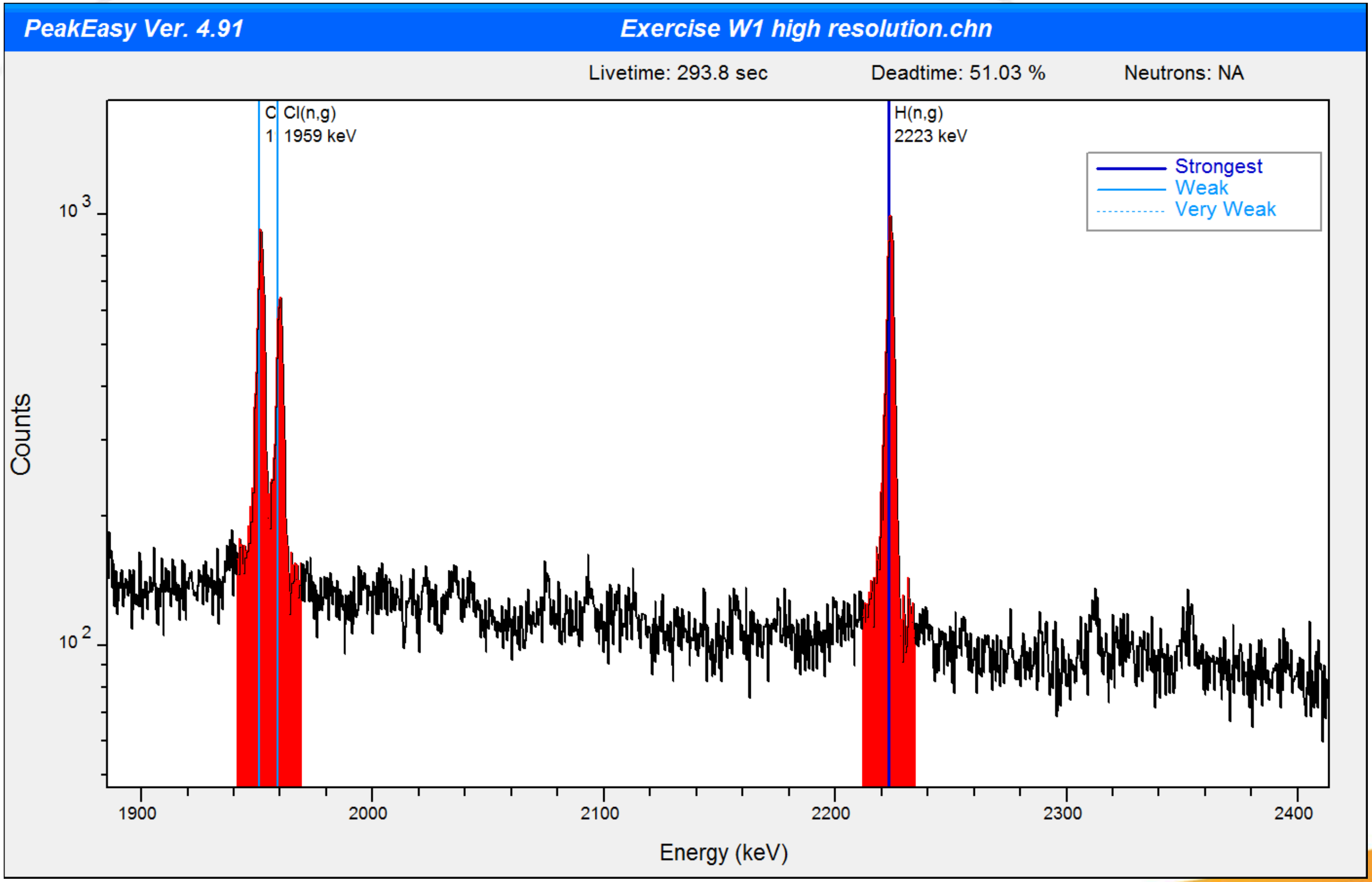
- Special instrumentation has been developed by JTOT to analyze for multiplication
  - The MC-15 is the next generation module developed by LANL and LLNL
- Multiplying masses of HEU, ^{233}U and ^{237}Np can also be analyzed for multiplication in addition to Pu
- The total SNM mass is established as well

Neutron Spectroscopy: "Unfolded" Neutron Spectra



Can differentiate between neutron sources and SNM
But not very well between SNM materials

Neutron Signatures in Gamma Ray Spectra: Capture Lines



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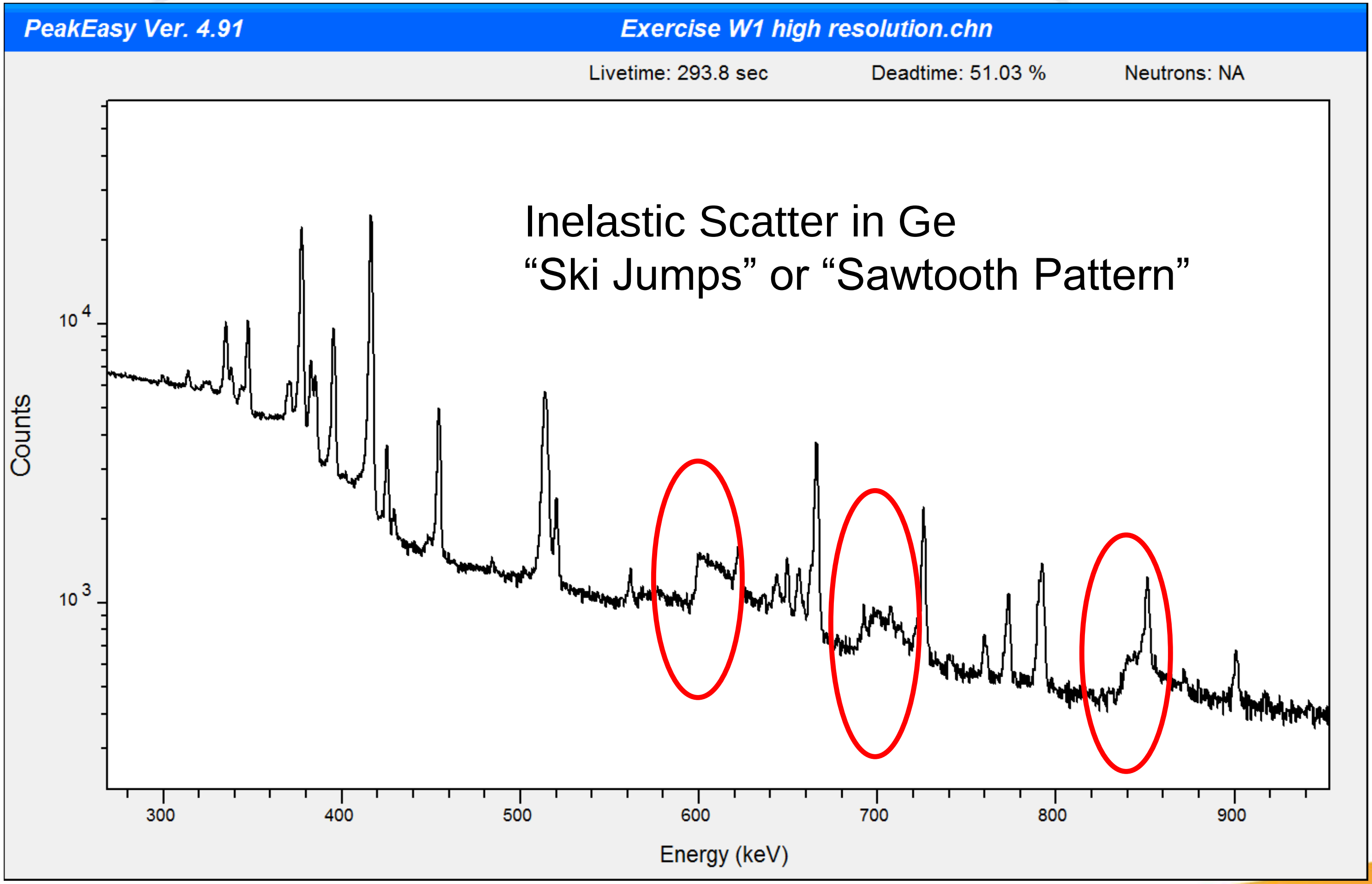
Evidence of Neutrons: Inelastic Scatter in HPGe



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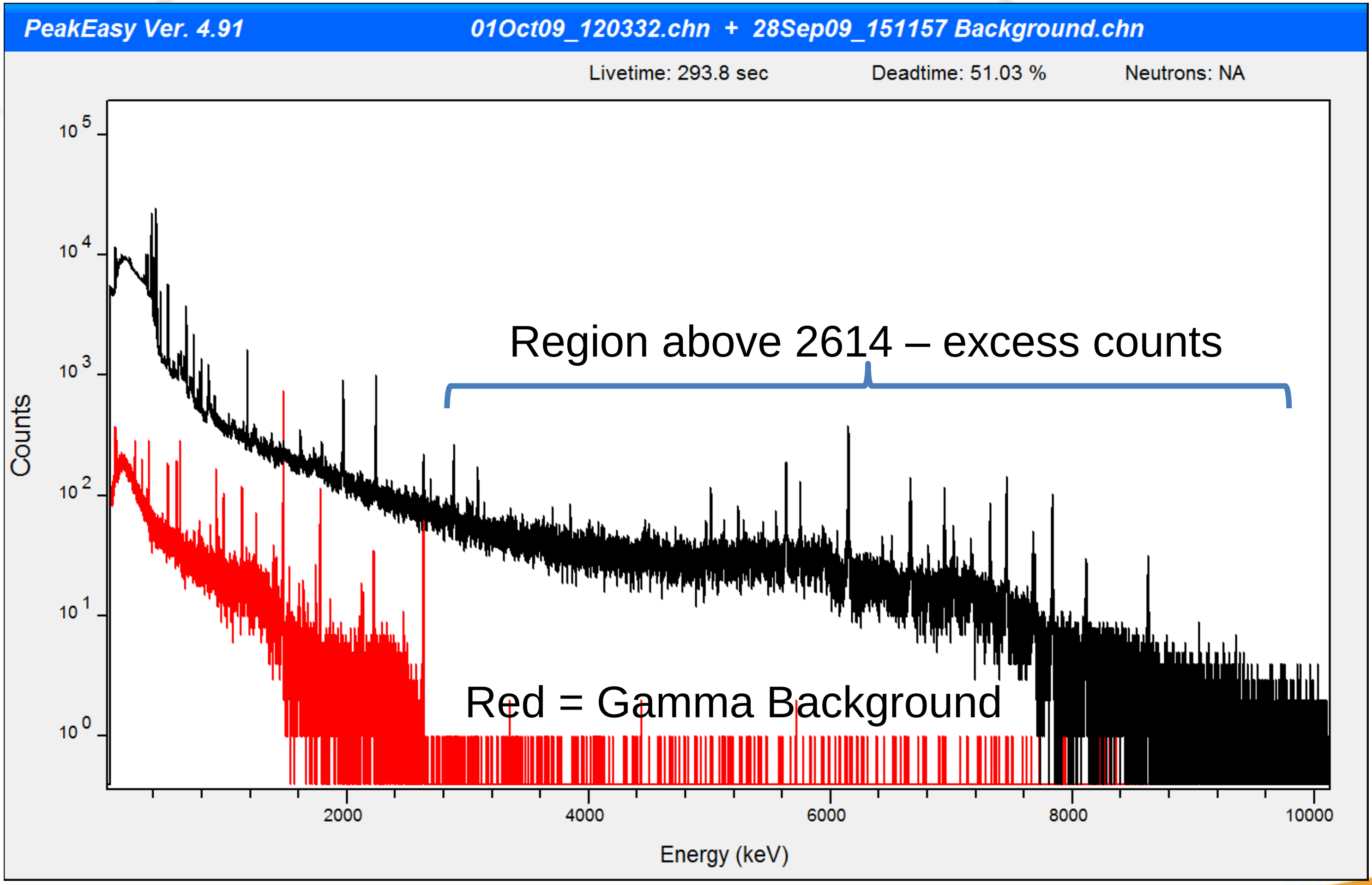
Evidence of Neutrons: Elevated Continuum Above 2614 keV



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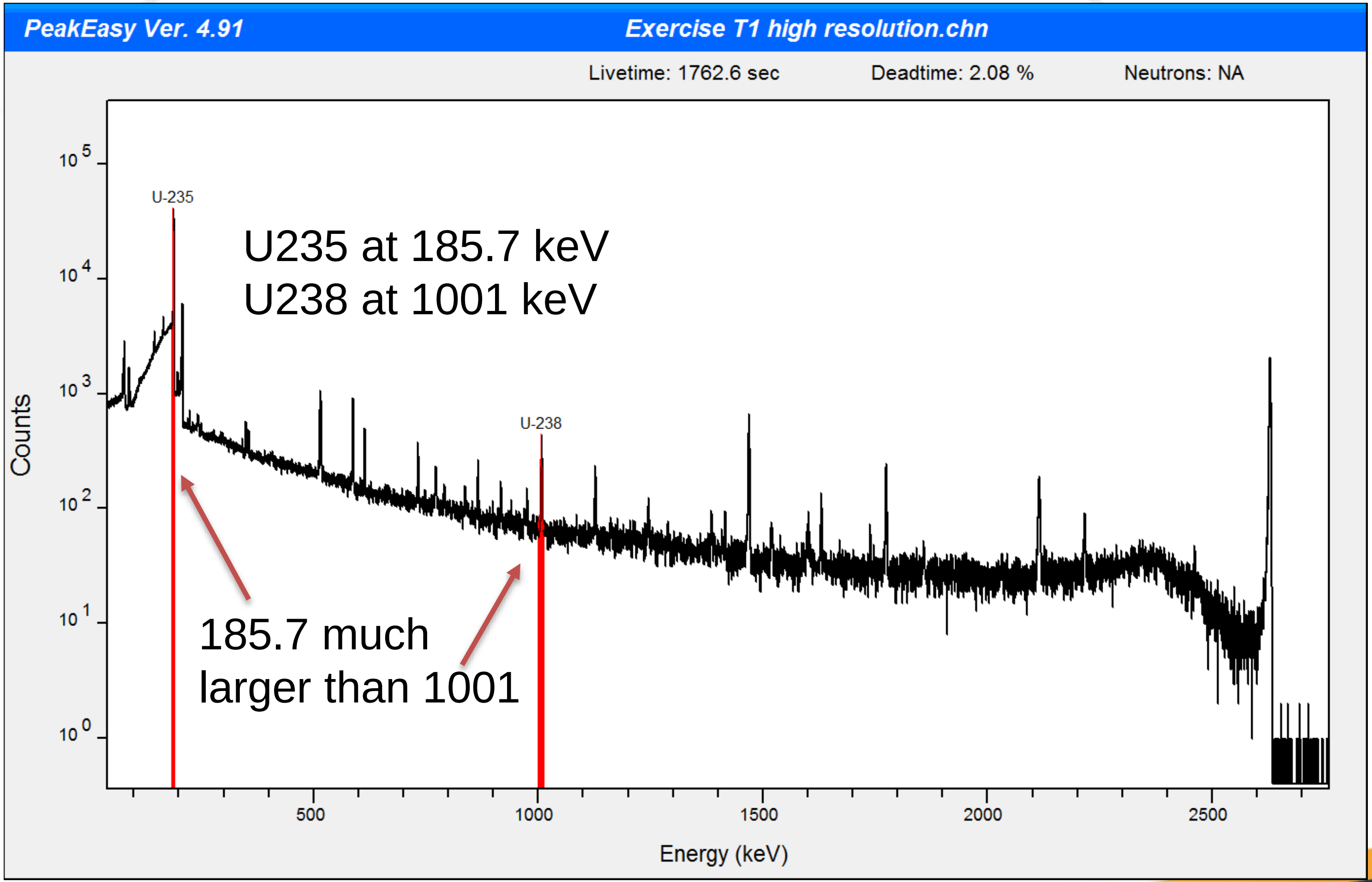
Gamma Signatures in SNM

- HEU: Mostly low E gammas: 144, 163, 186 and 205 keV
- ^{239}Pu: Gammas low to medium energy:129, 375, 414 and 646 keV are most apparent)
  - Over 160 total gamma emissions from ^{239}Pu
- ^{237}Np: Gammas from ^{233}Pa daughter are most intense at medium energies: 312, 340, 375 and 416 keV
- ^{233}U: Weak gammas at medium energies
  - Most intense gammas from ^{232}U (at ppm concentrations)
- ^{238}U: Gammas from ^{234m}Pa daughter at 740-1000 keV (766.4 and 1001.0 keV) plus others from 1700-1950 keV

Selected Measurements: HEU with ^{235}U and ^{238}U



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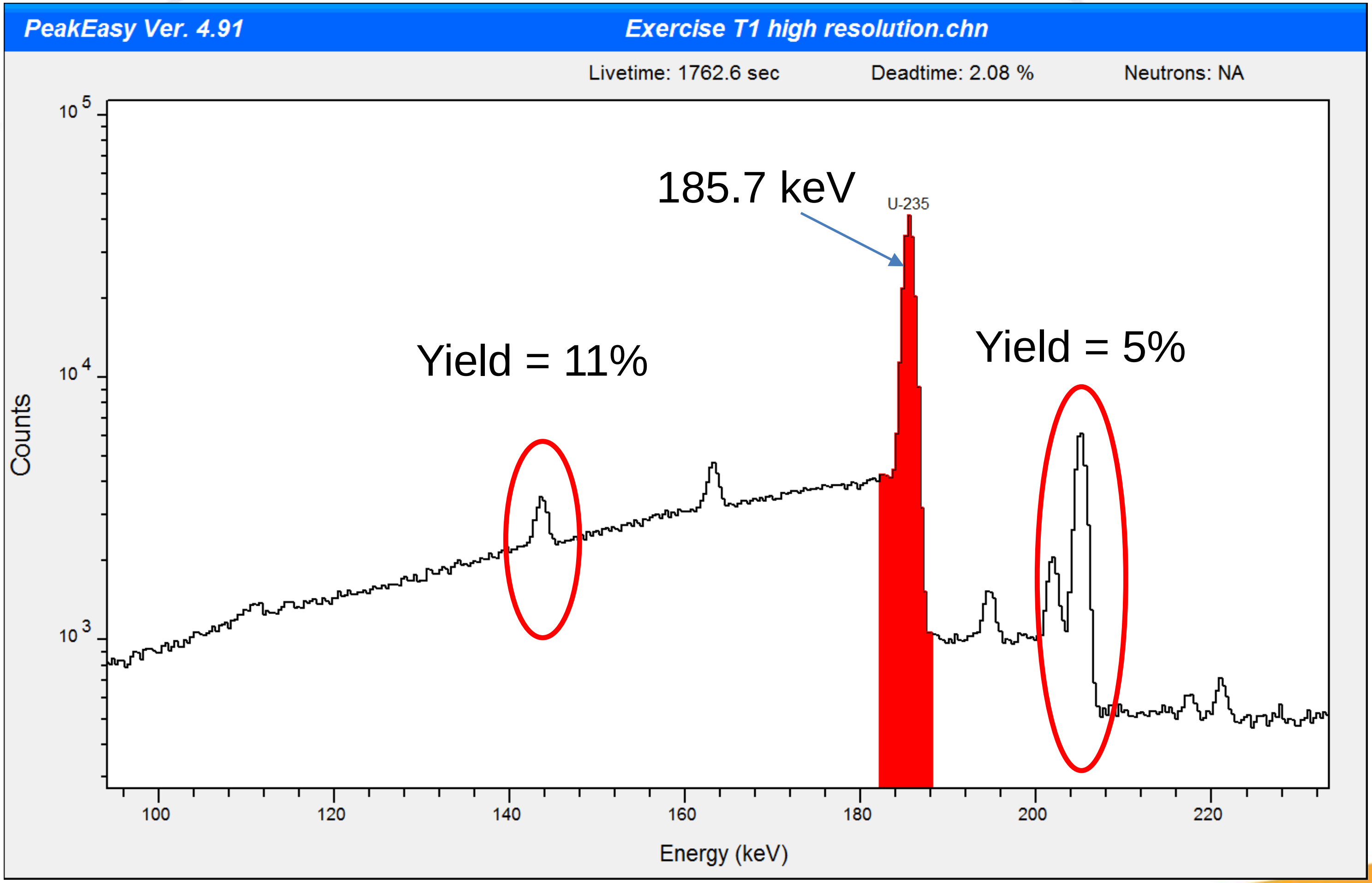
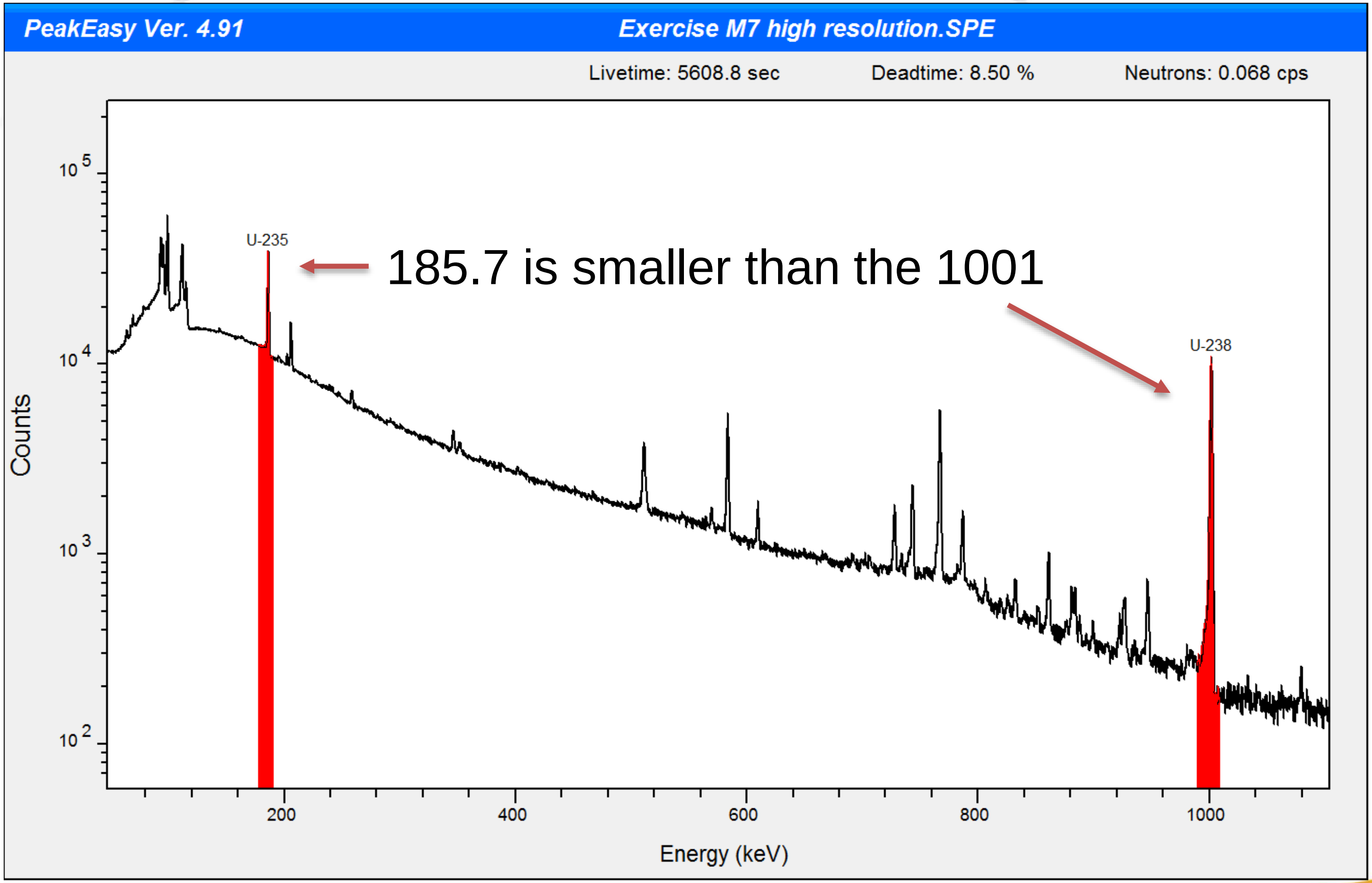
Upon Closer Scrutiny: Could the HEU be Shielded?



HEU or Natural Uranium?



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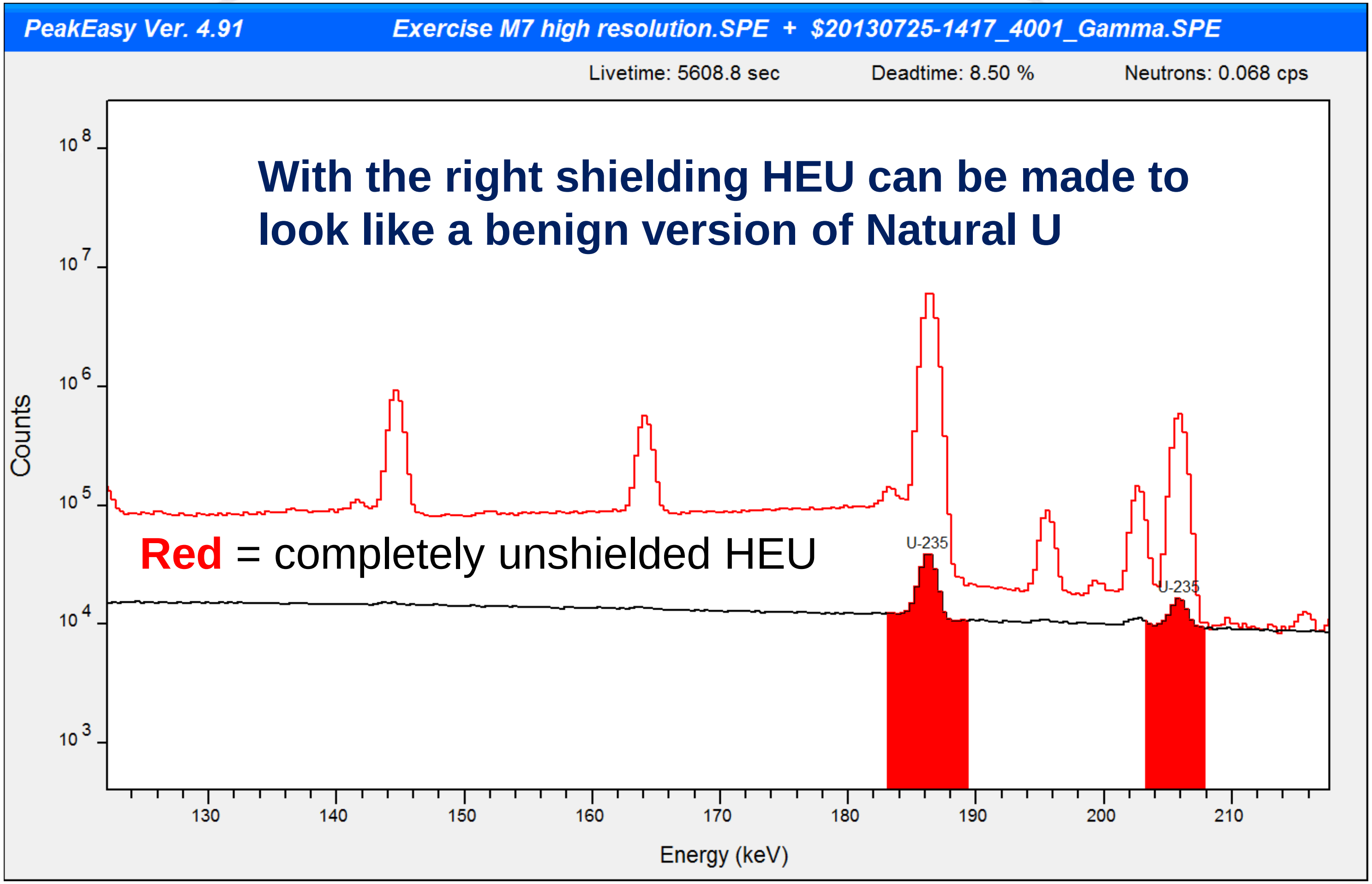
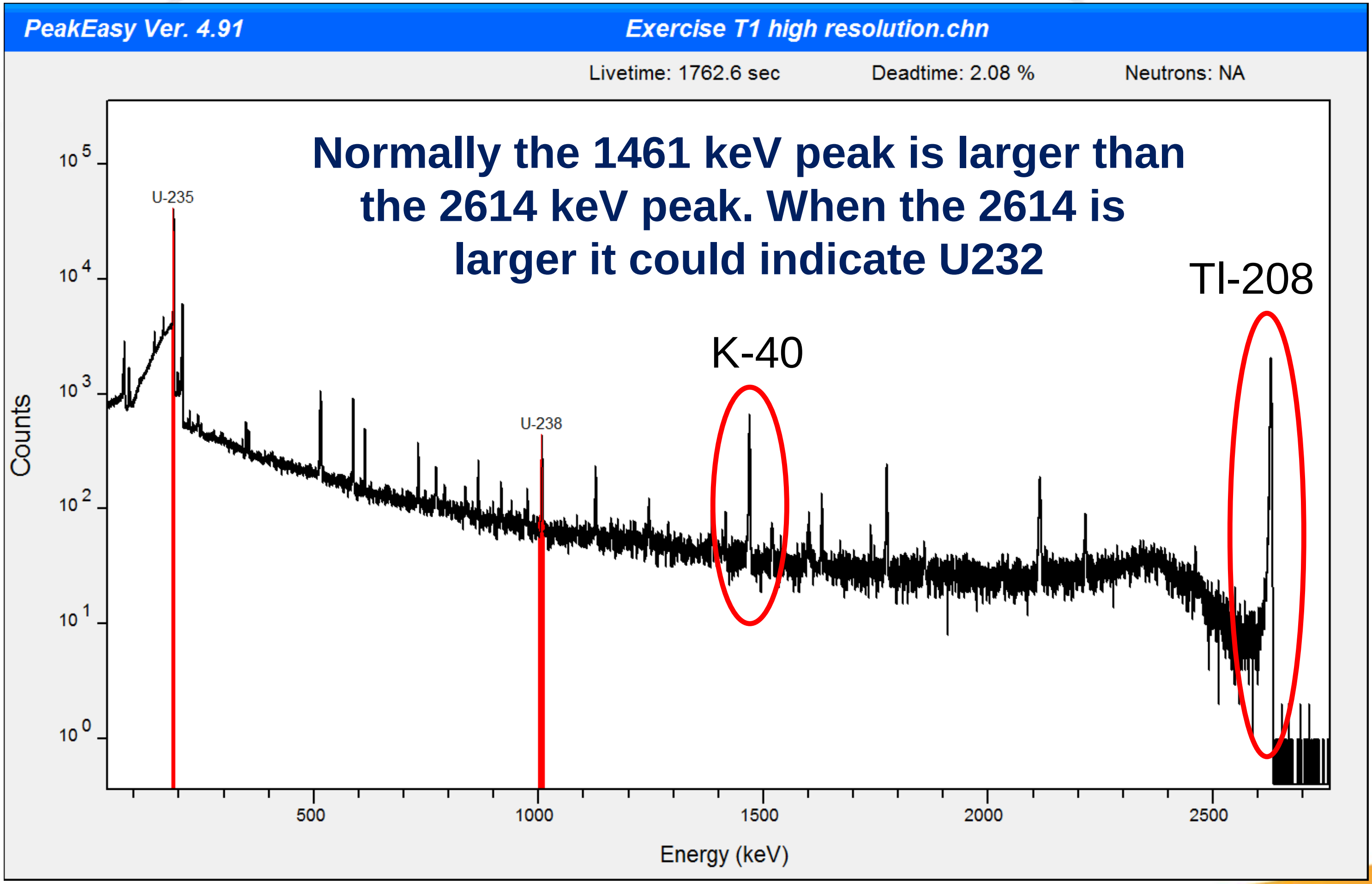
Hmmm…



PeakEasy Ver. 4.91
Exercise M7 high resolution.SPE + $20130725-1417_4001_Gamma.SPE
Livetime: 5608.8 sec
Deadtime: 8.50 %
Neutrons: 0.068 cps
With the right shielding HEU can be made to look like a benign version of Natural U
Red = completely unshielded HEU
U-235
U-235
Counts
Energy (keV)

More on HEU



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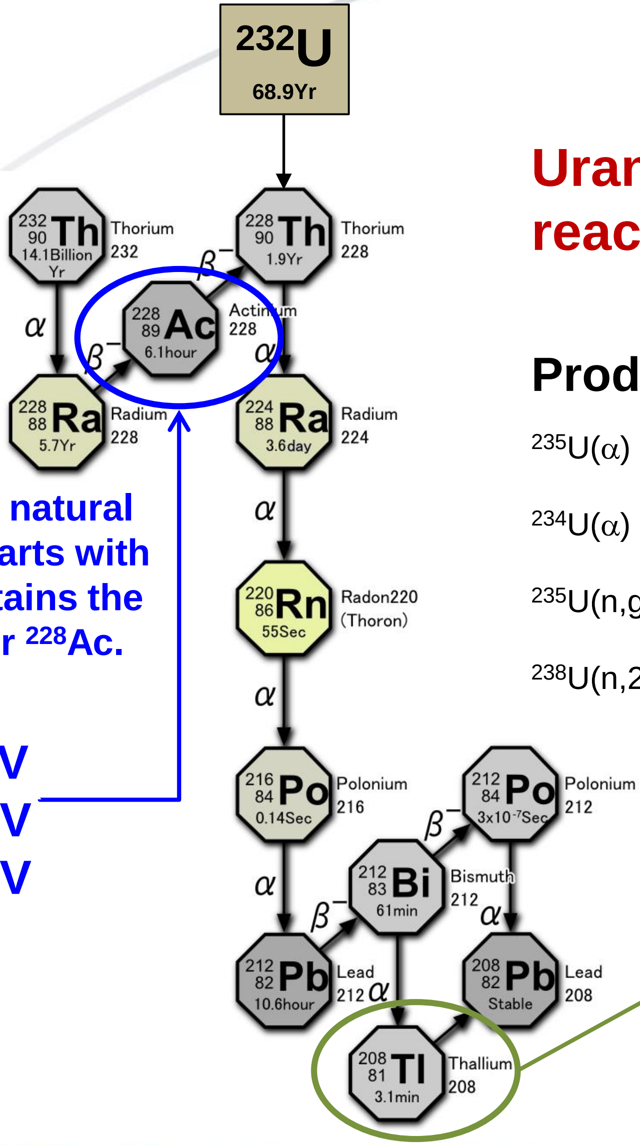
^{232}U in Recycled U



Uranium that has been through a reactor (recycled) contains ^{232}U .

Thorium in the natural background starts with ^{232}Th, and contains the decay daughter ^{228}Ac.

911 keV
969 keV
338 keV

Production of ^{232}U in a Reactor:

^{235}U(α) $\rightarrow$ ^{231}Th(β-) $\rightarrow$ ^{231}Pa(n,γ) $\rightarrow$ ^{232}Pa(β-) $\rightarrow$ ^{232}U

^{234}U(α) $\rightarrow$ ^{230}Th(n,γ) $\rightarrow$ ^{231}Th(β-) $\rightarrow$ ^{231}Pa(n,γ) $\rightarrow$ ^{232}Pa(β-) $\rightarrow$ ^{232}U

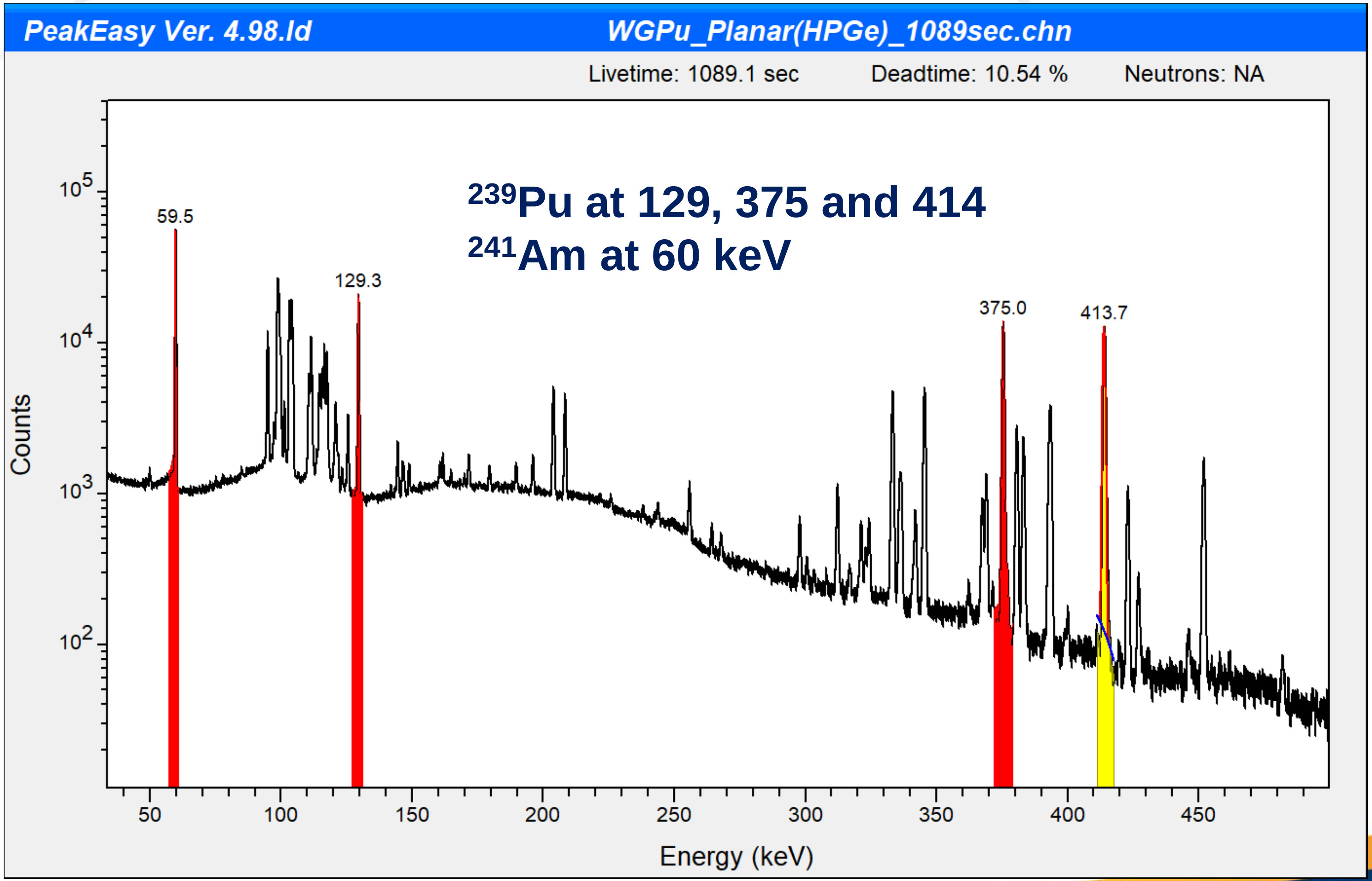
^{235}U(n,g) $\rightarrow$ ^{236}U(n,γ) $\rightarrow$ ^{237}U(β-) $\rightarrow$ ^{237}Np(n,2n) ^{236m}Np(β-) $\rightarrow$ ^{236}Pu(α) $\rightarrow$ ^{232}U

^{238}U(n,2n) $\rightarrow$ ^{237}U(β-) $\rightarrow$ ^{237}Np(n,2n) $\rightarrow$ ^{236m}Np(β-) $\rightarrow$ ^{236}Pu(α) $\rightarrow$ ^{232}U

2614 keV
861 keV
583 keV
239 keV

*Peurrung, A.J., "Predicting ^{232}U Content in Uranium", PNNL Document 12075

Plutonium!
Low Energy Gammas



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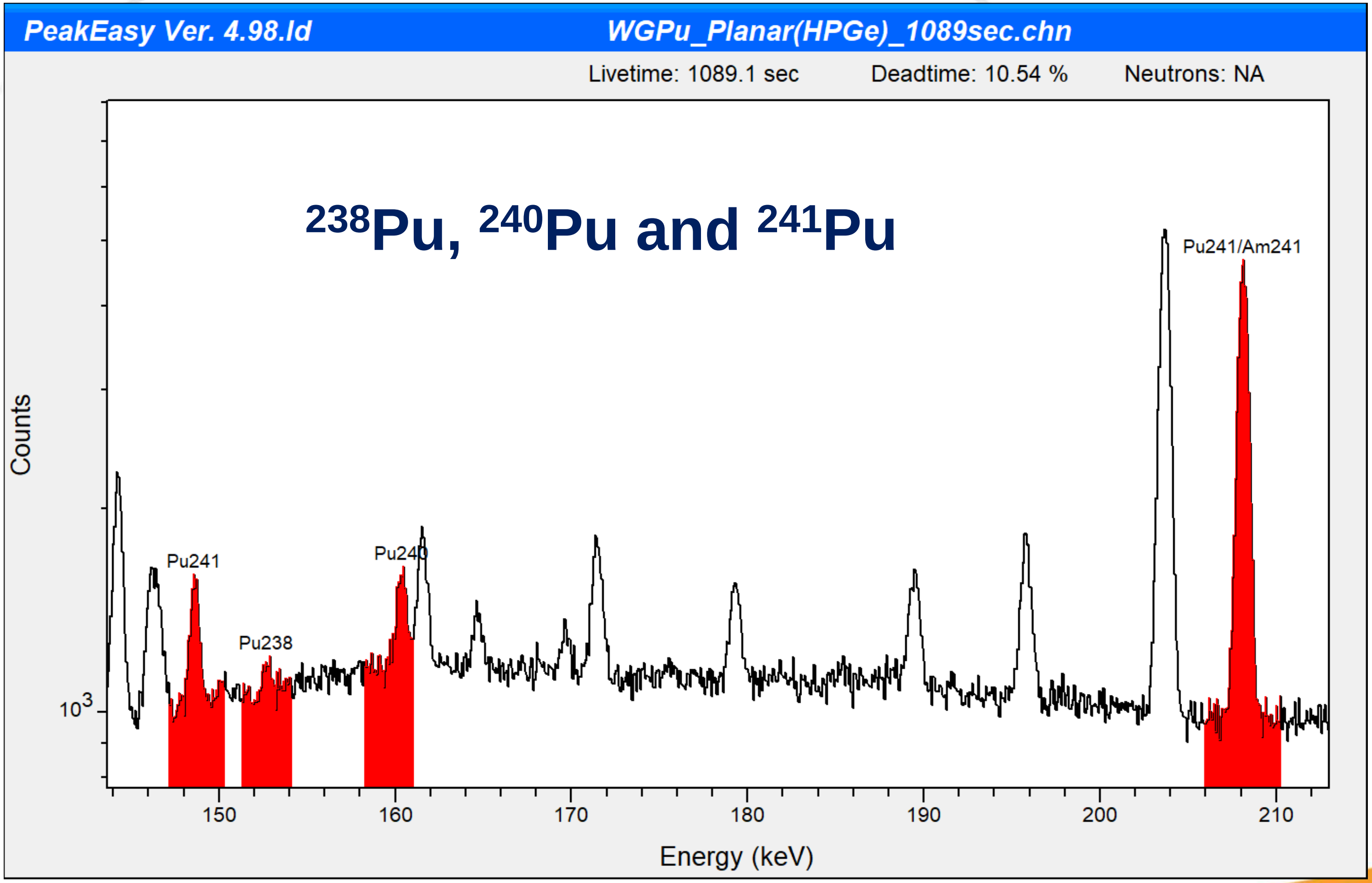
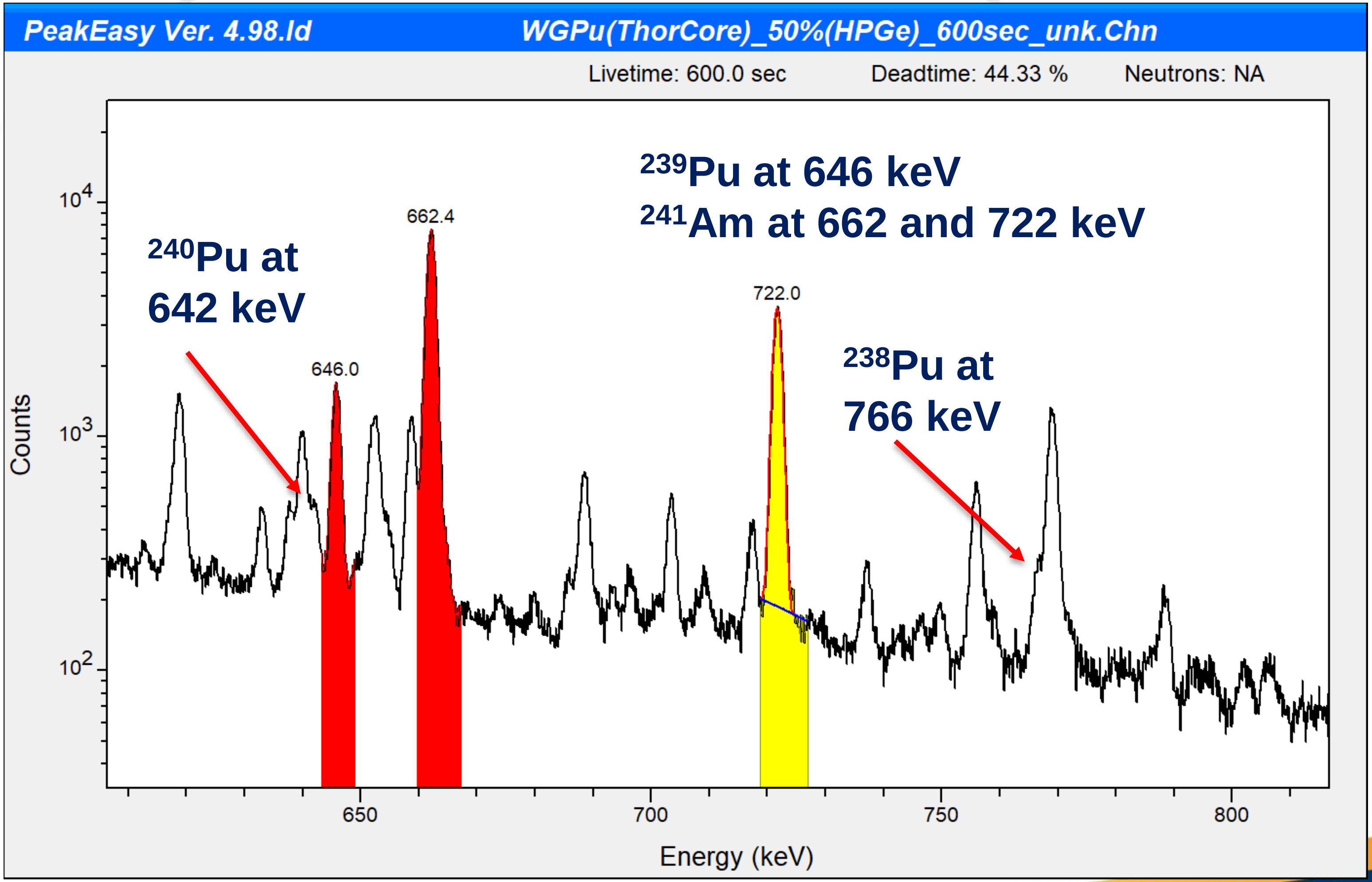
Other Isotopes at Low Energy



Plutonium: High Energy Gammas



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Demo FRAM Isotopic Routine

<u>F</u>ixed Energy <u>R</u>esponse Function <u>A</u>nalysis for <u>M</u>ultiple Efficiencies

FRAM also means “onward” or “forward” in Scandinavian

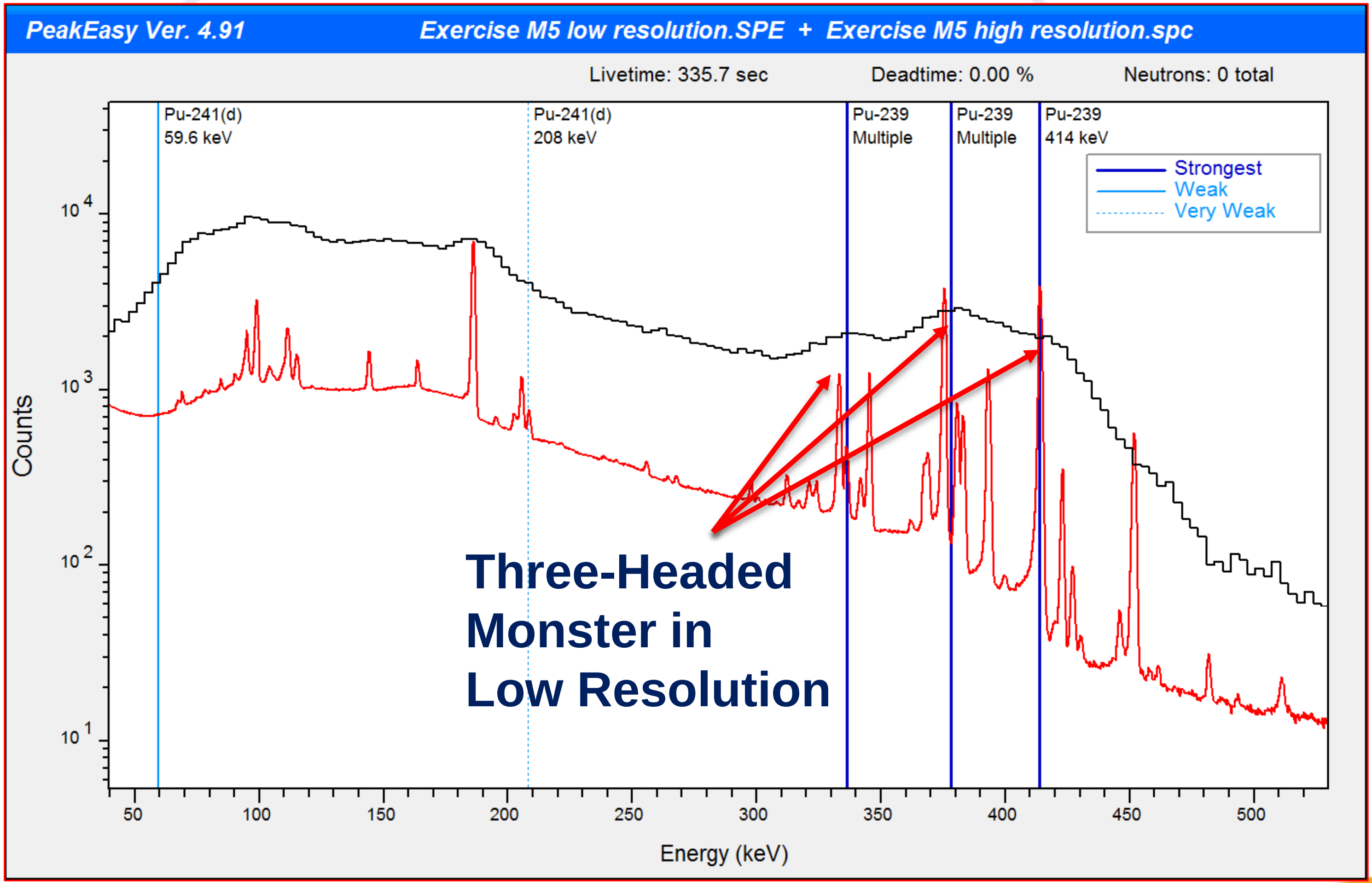
Demo PeakEasy Routine

Spectrum views in these slides are created with LANL's PeakEasy program (Dr. Brian Rooney is primary developer, Dr. Paul Felsher Project Mgr.)

PeakEasy is:

- A Great spectrum viewer
- An Exceptional gamma ray database
- A Superb user-interactive nuclide ID tool
- Soon to be Privatized for Public Use!

Low Resolution vs High Resolution



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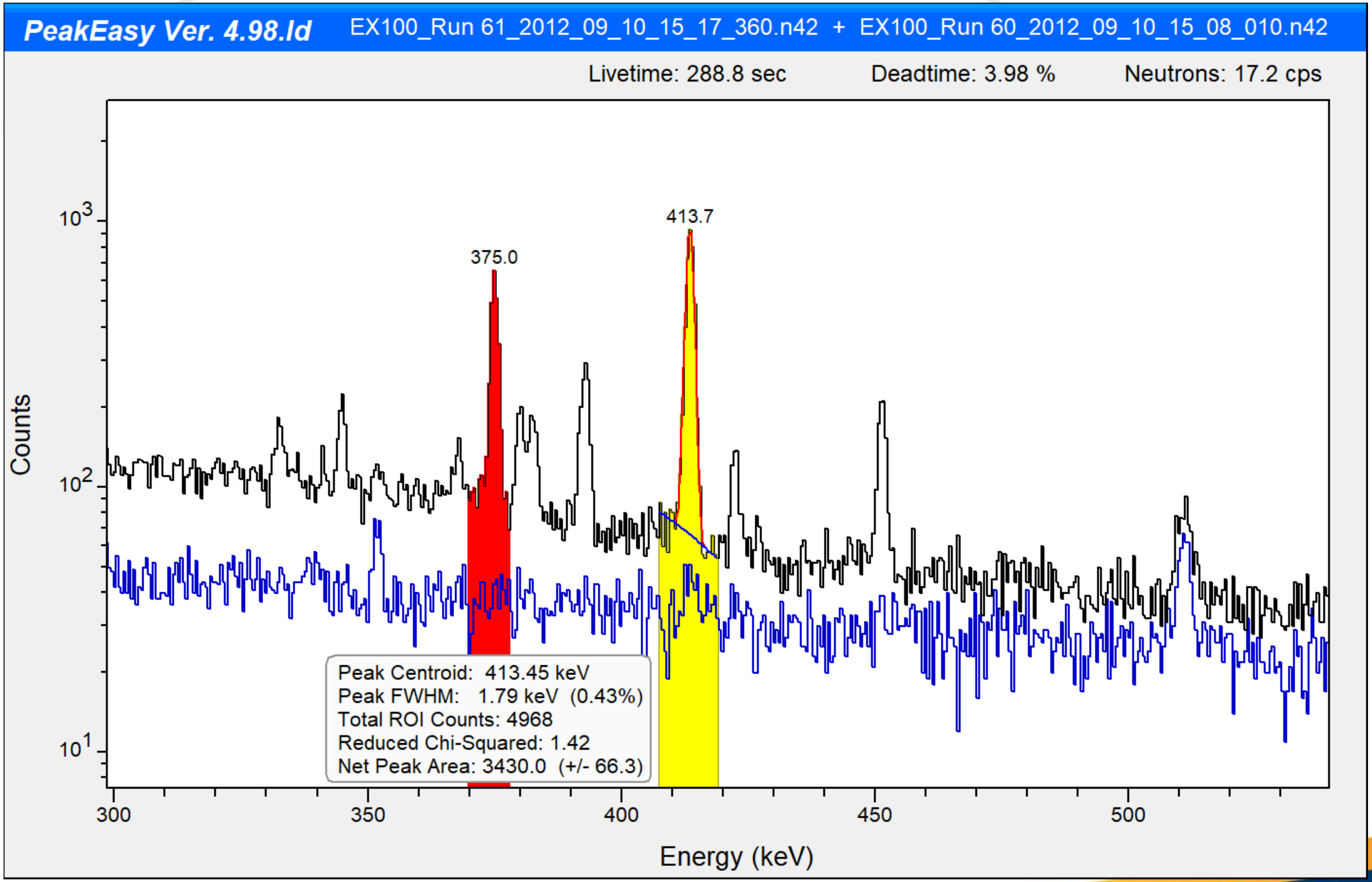
Tungsten Shielded WGPu



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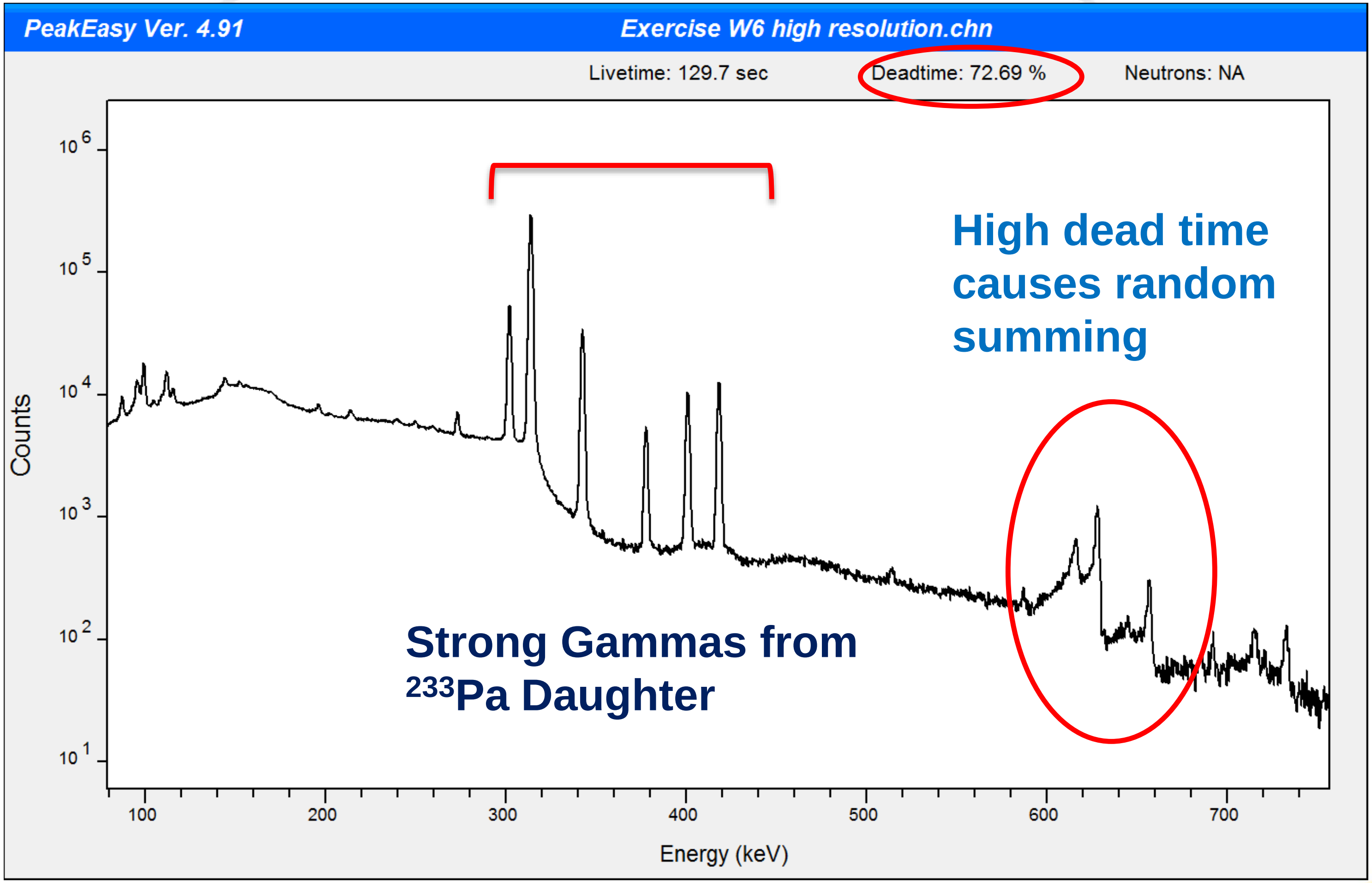
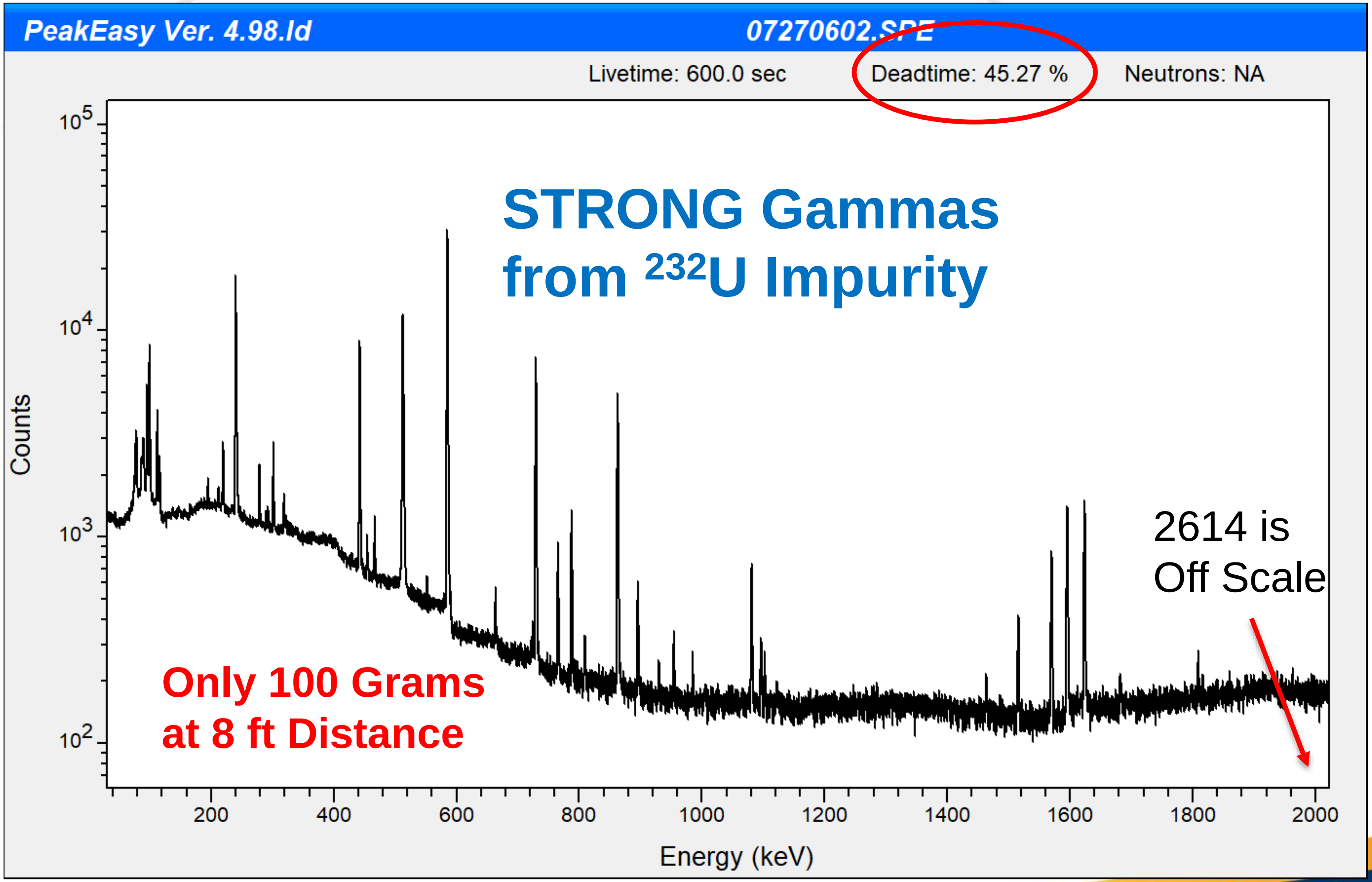
^{237}Np is Fissionable – Properties are Comparable to HEU



^{233}U is Highly Fissile – Also Highly Radioactive (Dose!)



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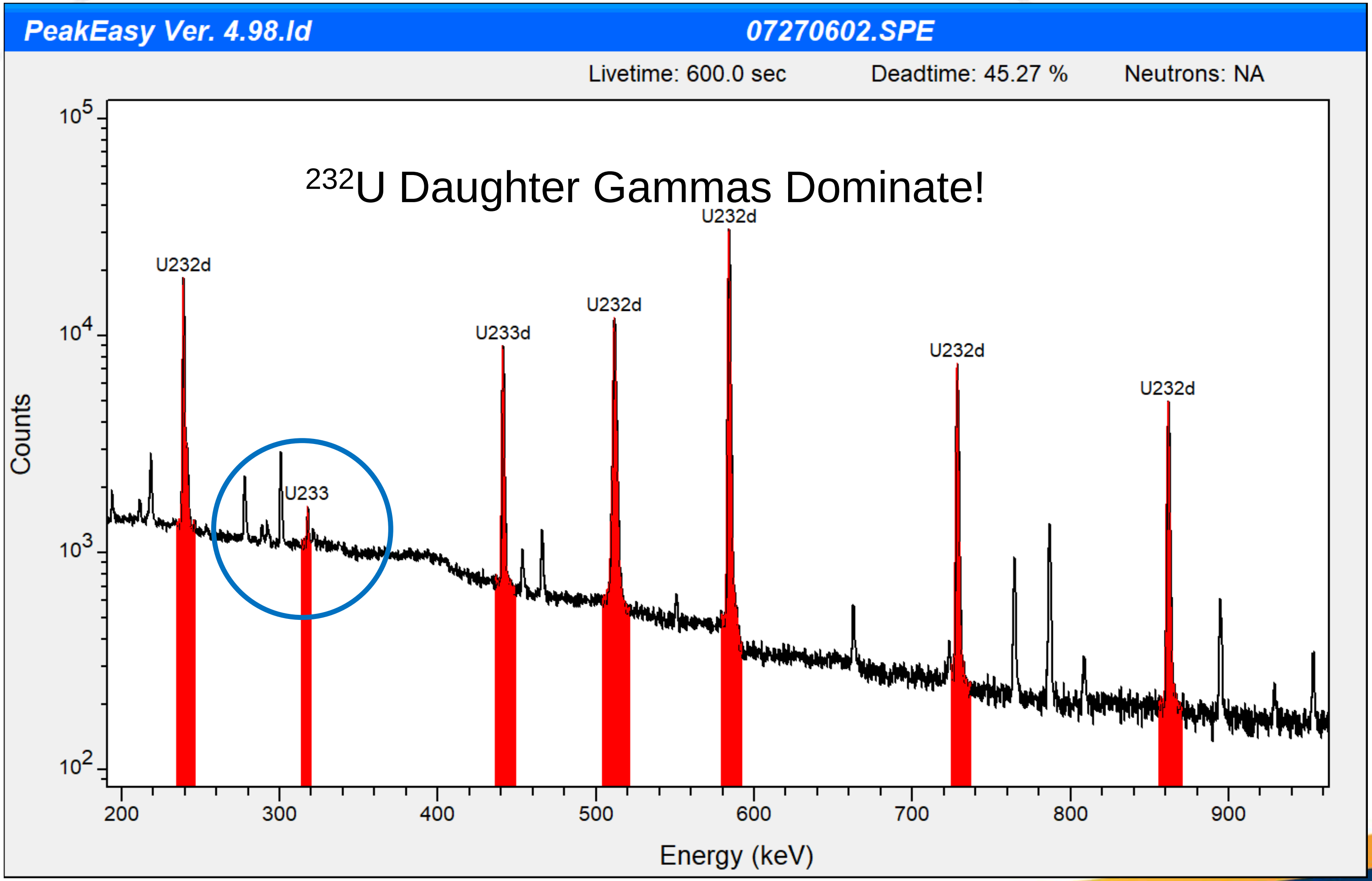
^{233}U Primary Signatures are Weak



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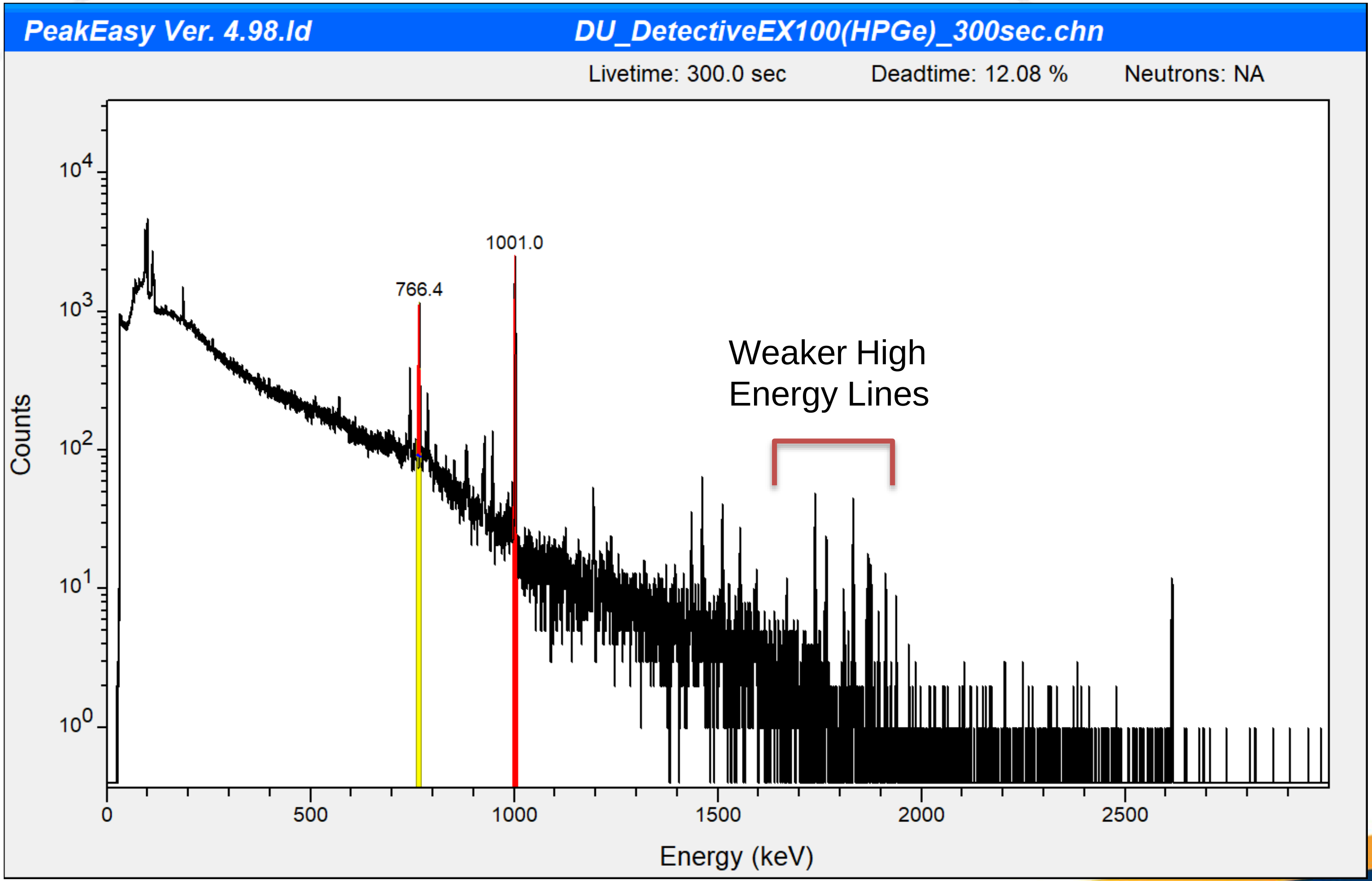
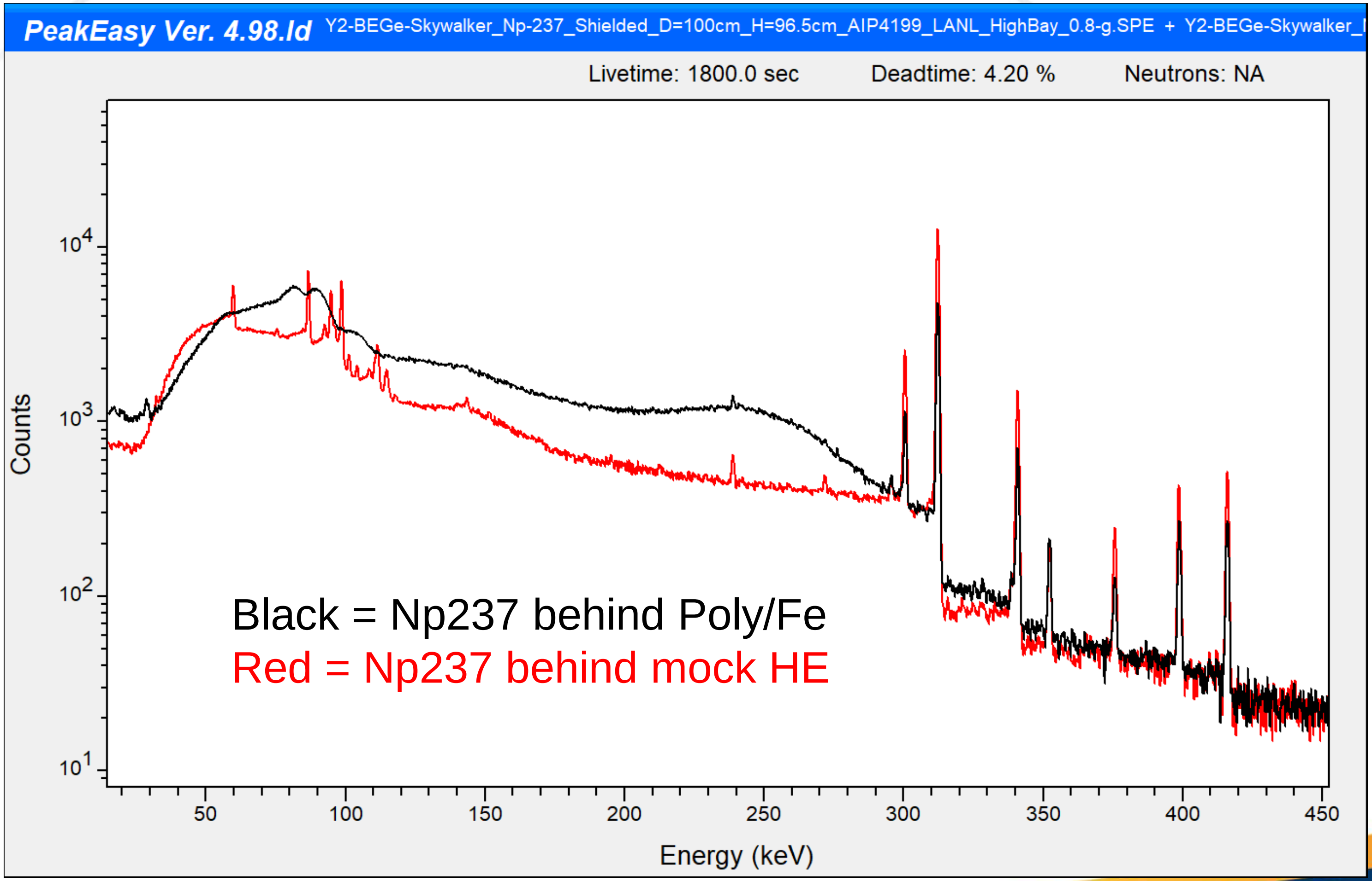
^{238}U Gammas Might be Present



What About Compton Signatures?



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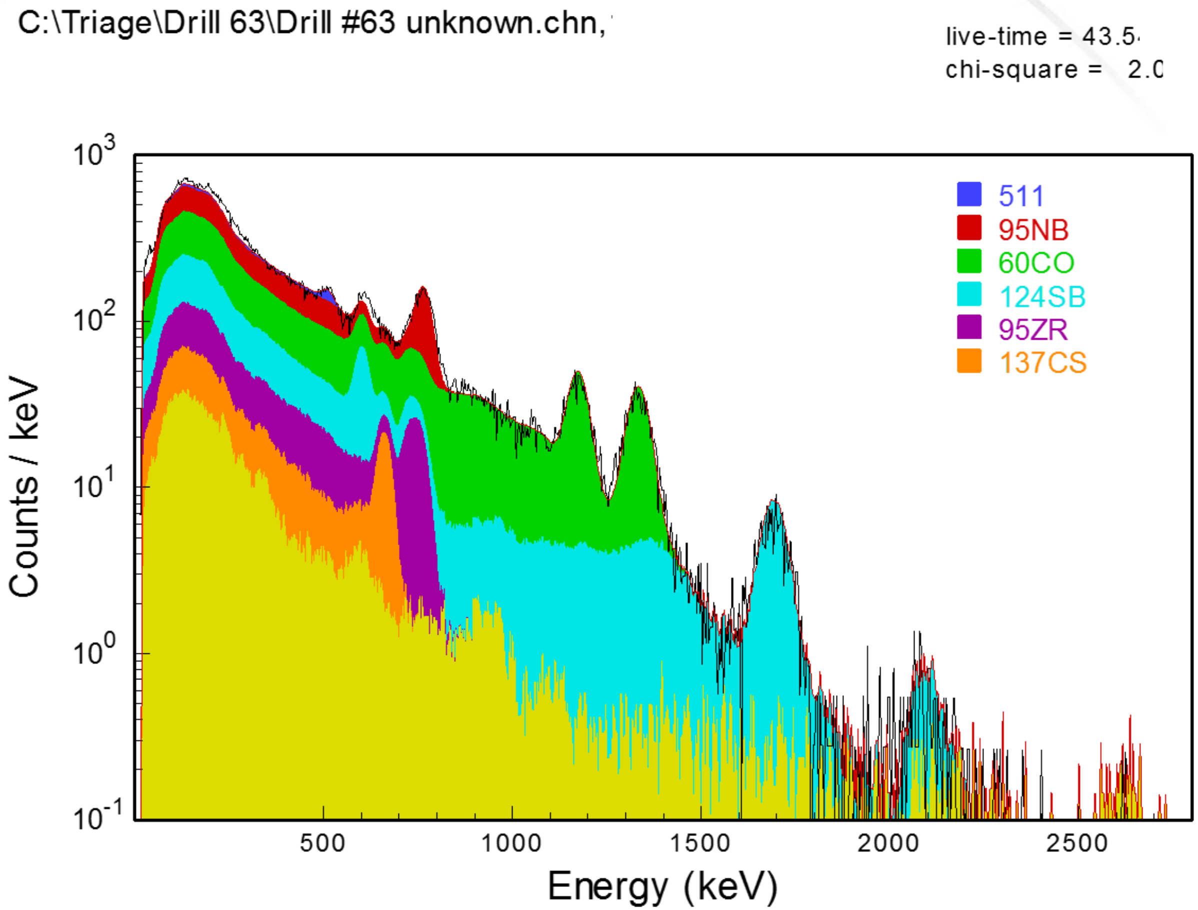
Analysis Tools - GADRAS



Muchos Gracias – Es un Placer!

- THANK YOU FOR HOSTING ME!

- GO RAMS!!!

- QUESTIONS?

Acknowledgment

- Many thanks to the Department Of Energy Nuclear Emergency Response Program at the Los Alamos National Laboratory for funding this presentation
- Thanks also to my LANL Colleagues for their part in creating portions of this presentation as part of previous efforts
  - Dr. Paul Felsher
  - Dr. Brian Rooney
  - Dr. Peter Karpius
  - Dr. Marcie Lombardi
  - Dr. Mark Nelson (CSU alumnus)
  - Mr. Brian Rees, CHP
  - Dr. Katrina Stults